Conical Probe Calibration and Wind Tunnel Data Analysis of the Channeled Centerbody Inlet Experiment

Samson S. Truong, Co-op

Mentor: Mike Frederick

RA – Aerodynamics Group

Cal Poly San Luis Obispo

Senior – Aerospace Engineering

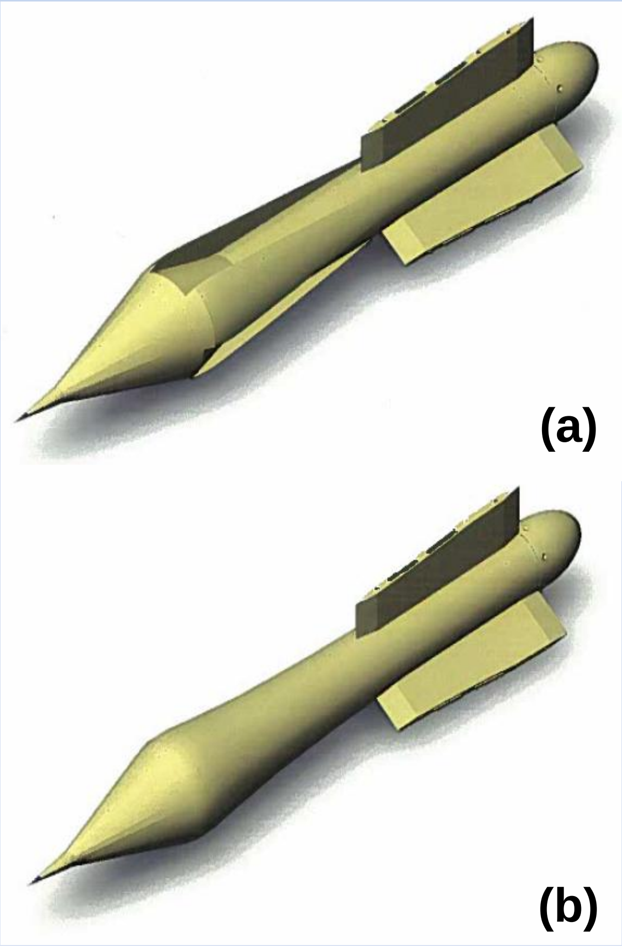
05/04/11

Overview

- Intro - What is the CCIE and its objectives?
- Project – Conical Probe Calibration
  - What and why a calibration is needed?
  - Calibration Process
  - Uncertainty Analysis
  - Develop the In-Flight RTF Script
- Relation to DFRC Strategic Plan
- Questions

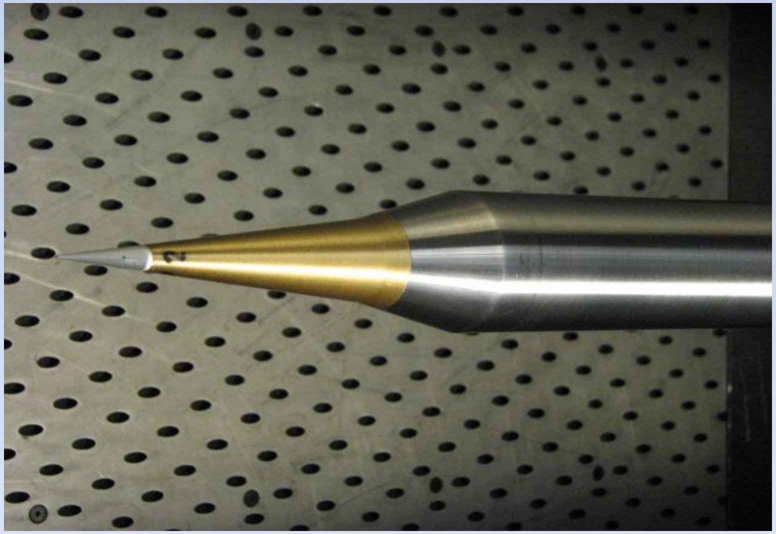
Channeled Centerbody Inlet Experiment (CCIE)

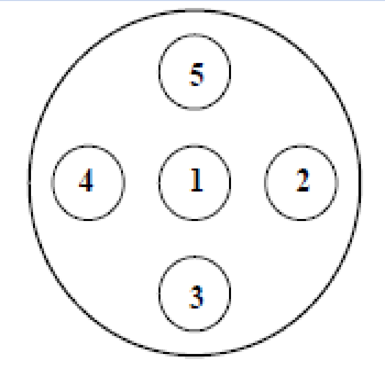
- Bi-conic supersonic inlet integrating a fixed geometry design allowing a larger cross-sectional area for mass flow during optimal off-design Mach conditions
- Concept developed by TechLand Research, Inc. through NASA SBIR contract
- **Research Objectives**:
  - ➢ Define the inlet flow (i.e. mass flow, pressure recovery, distortion):
    - ▪ **Channeled Centerbody (a)**
    - ▪ **Smooth Centerbody (b)**
  - ➢ Compare the results to CFD analysis



The Conical Multi-Hole Probe

- Mounted at front of CCIE
- Consists of 5 pressure ports:
  - 1 total: P_1
  - 4 static: $P_{2,}$ $P_{3,}$ $P_{4,}$ P_5
- Angle of Attack (α) measured along vertical axis
- Sideslip angle (β) measured along horizontal axis
- Probe holder in wind tunnel cannot traverse in horizontal direction. As a result, probe must be rolled in order to gather sideslip data.





Conical Probe Calibration

- Wind tunnel testing was the preferred method to generate calibration data for the conical multi-hole probe.
- Calibration allows us to use the probe for determination of the flow properties in front of the inlet in real time during flight.
- Local Mach will be used to help guide the pilot to the desired research test points.
- Calibration test points include:
  - Mach 1.2
  - Mach 1.3
  - Mach 1.46
  - Mach 1.69

Calculate Initial Wind Tunnel Parameters & Plot Misaligned Data

- Calculate following parameters from measured pressures:
  - Average Static Pressure (P_a)
  - Angle of Attack Pressure Coefficient (C_α)
  - Sideslip Angle Pressure Coefficient (C_β)
  - Total Pressure Coefficient (C_t)
  - Static Pressure Coefficient (C_s)
- Create calibration maps based on these parameters to determine equations to calculate critical in-flight variables.

$$P_a = \frac{1}{4}(P_2 + P_3 + P_4 + P_5)$$

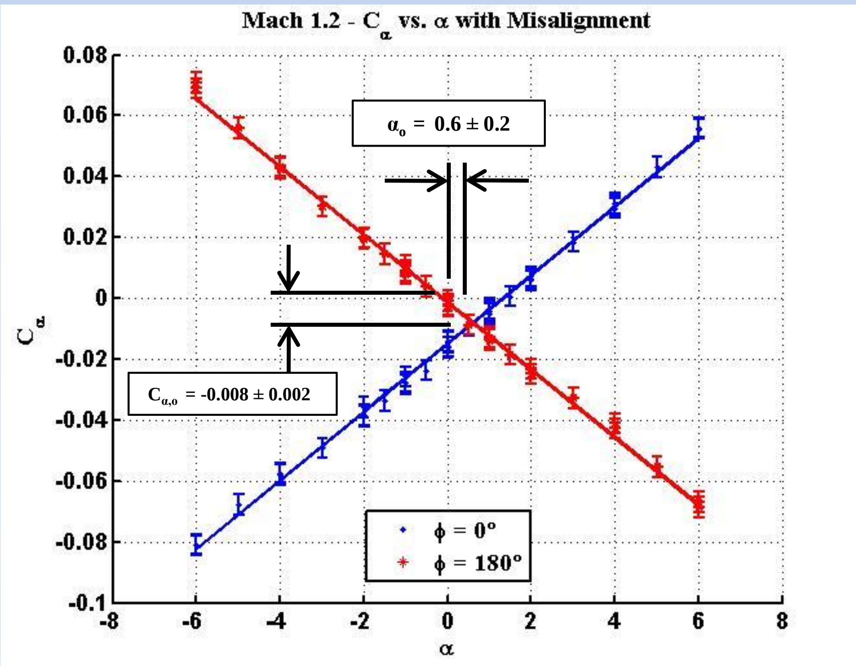
$$C_\alpha = \frac{P_3 - P_5}{P_1 - P_a}$$

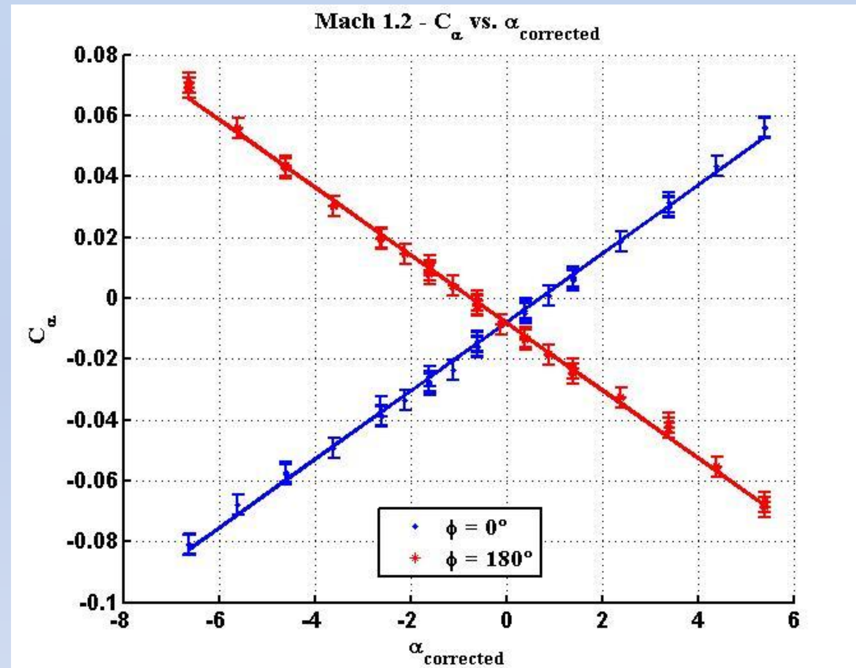
$$C_\beta = \frac{P_4 - P_2}{P_1 - P_a}$$

$$C_t = \frac{P_1 - P_o}{P_1 - P_a}$$

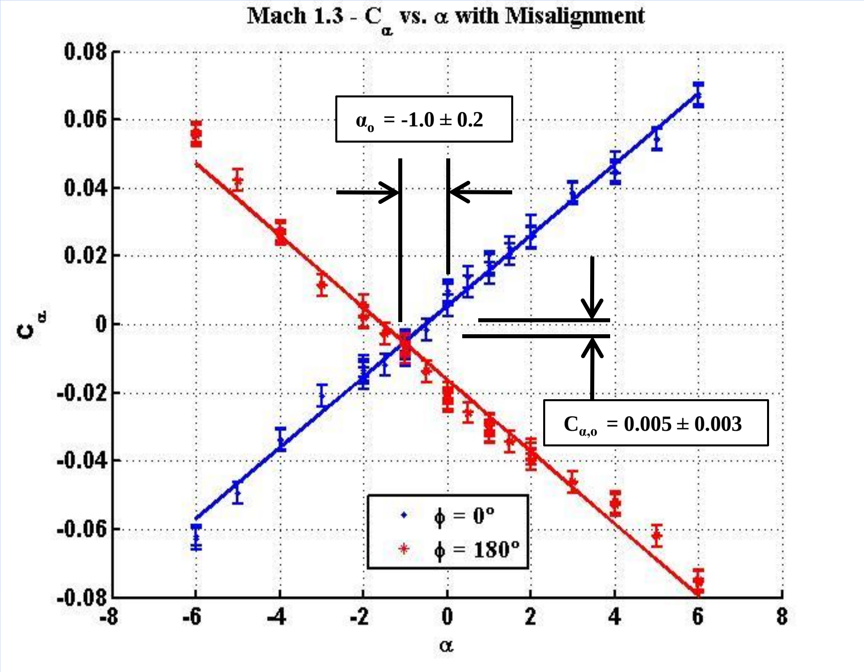
$$C_s = \frac{P_1 - P_s}{P_1 - P_a}$$

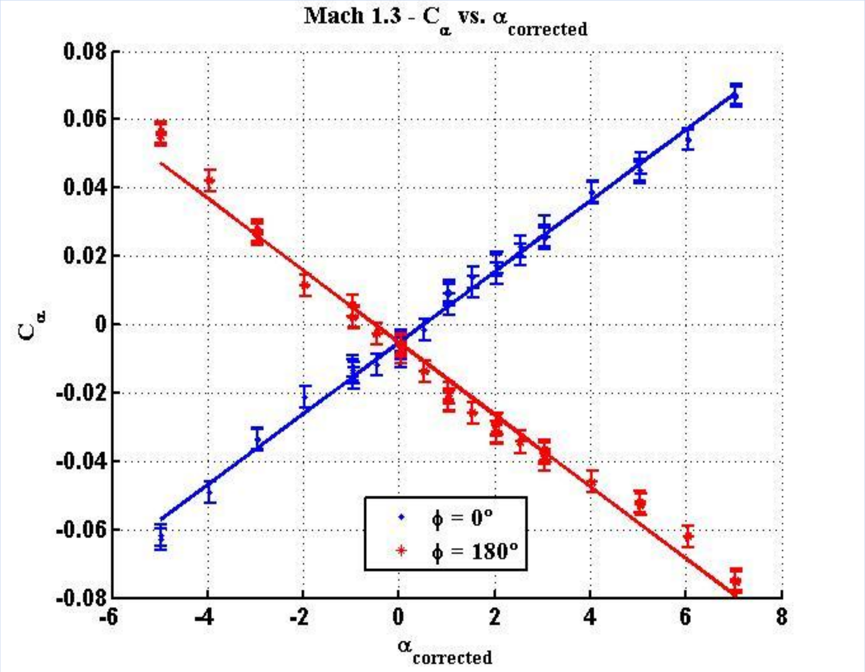
Mach 1.2 – Angle of Attack Case



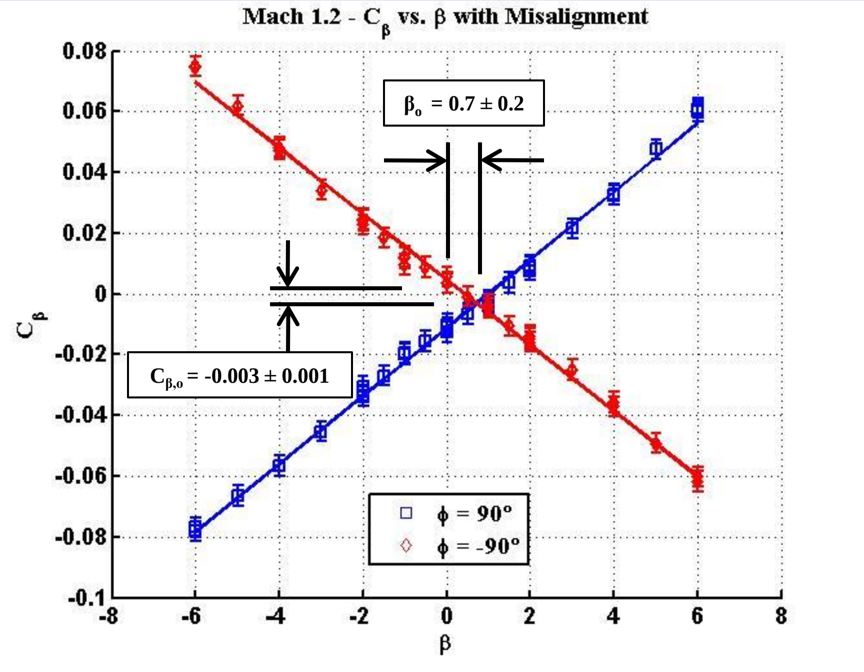


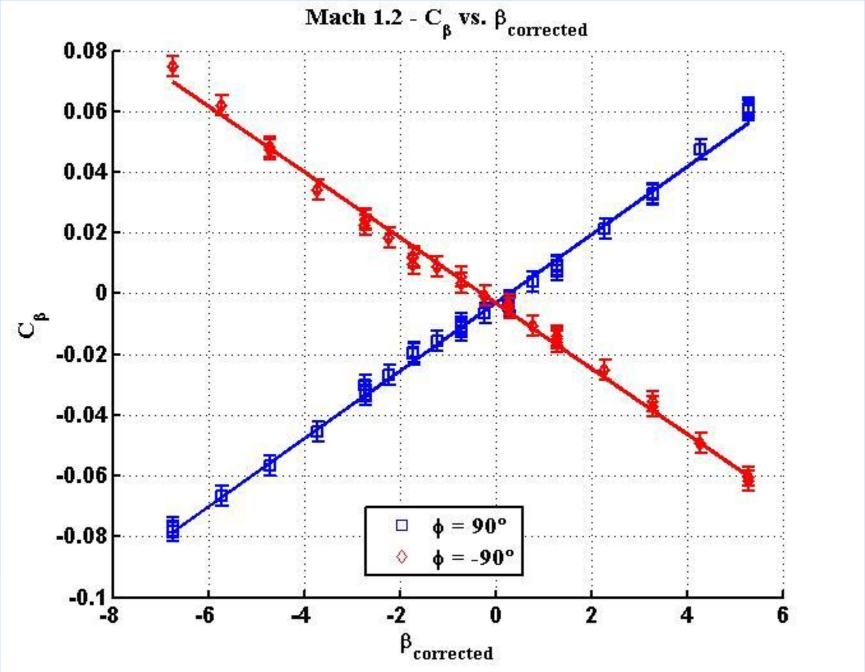
Mach 1.3 – Angle of Attack Case



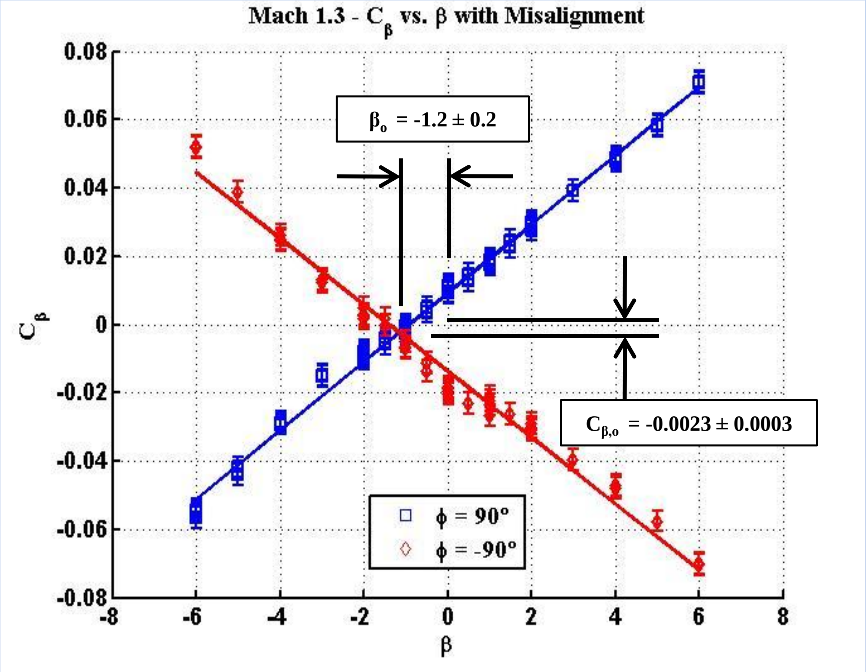


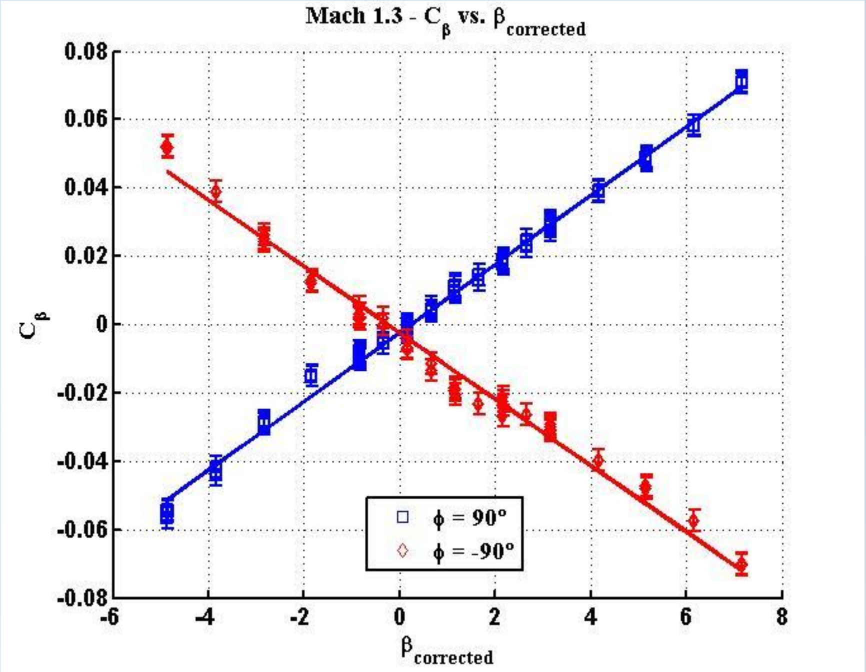
Mach 1.2 – Sideslip Angle Case





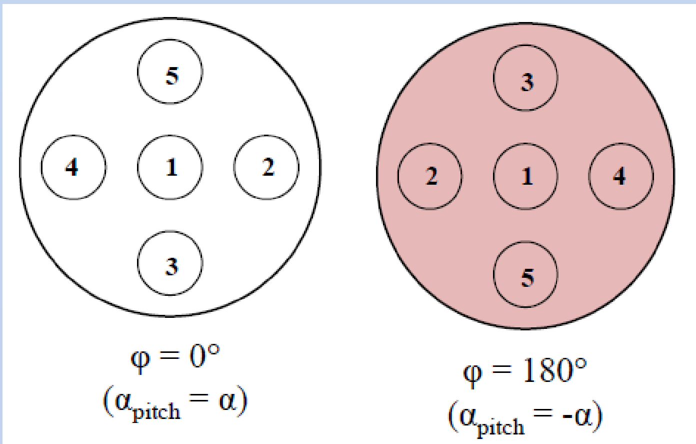
Mach 1.3 – Sideslip Angle Case



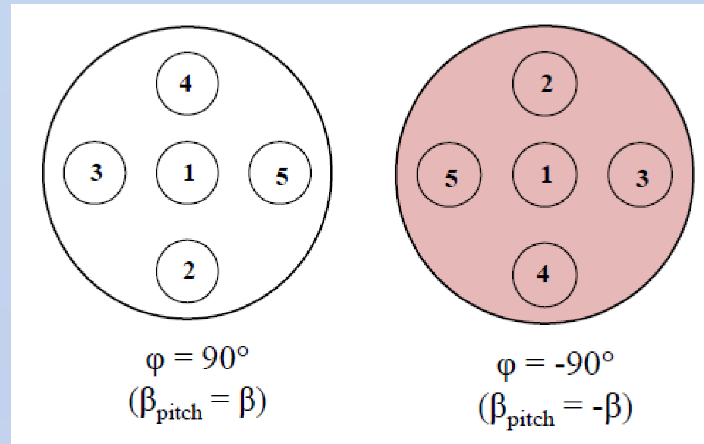


Probe Orientation Correction

α_{pitch}



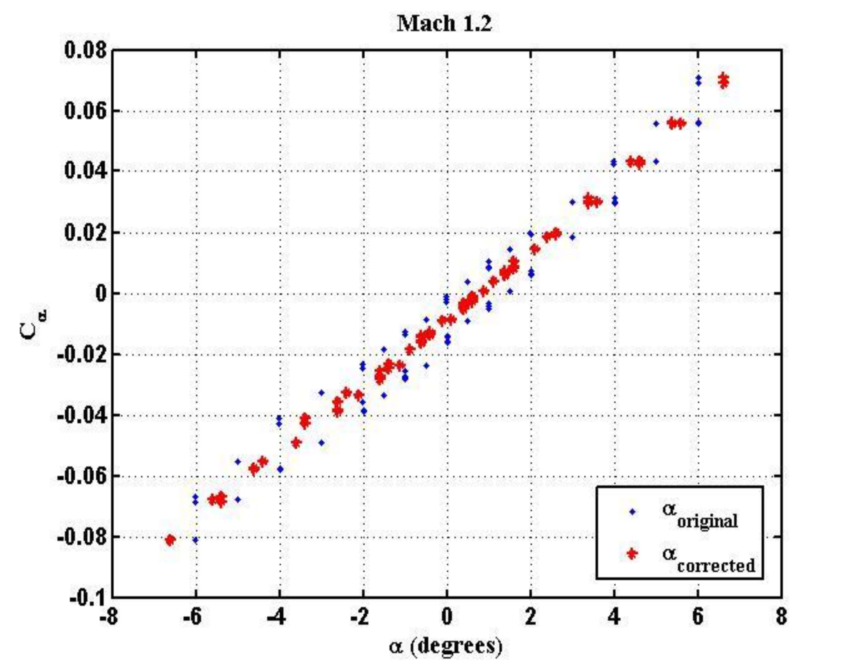
β_{pitch}

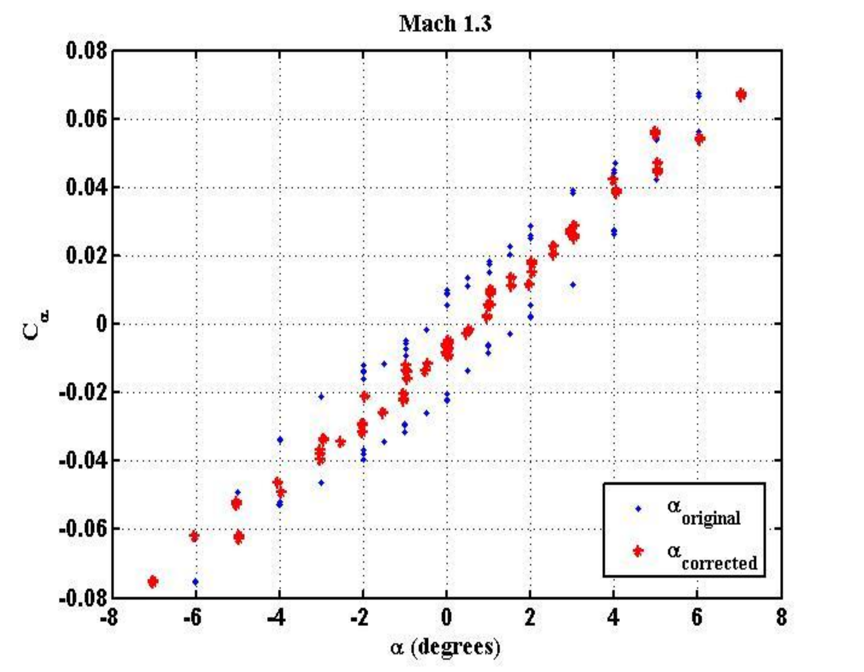


- Roll orientations of $\varphi = 180°$ & $\varphi = -90°$ (in red) have static ports switched in vertical and horizontal planes as opposed to $\varphi = 0°$ & $\varphi = 90°$.
- If roll angles were any other, angular transformations would have to be used in order correct the probe orientation.

Determine α and β-Polynomials

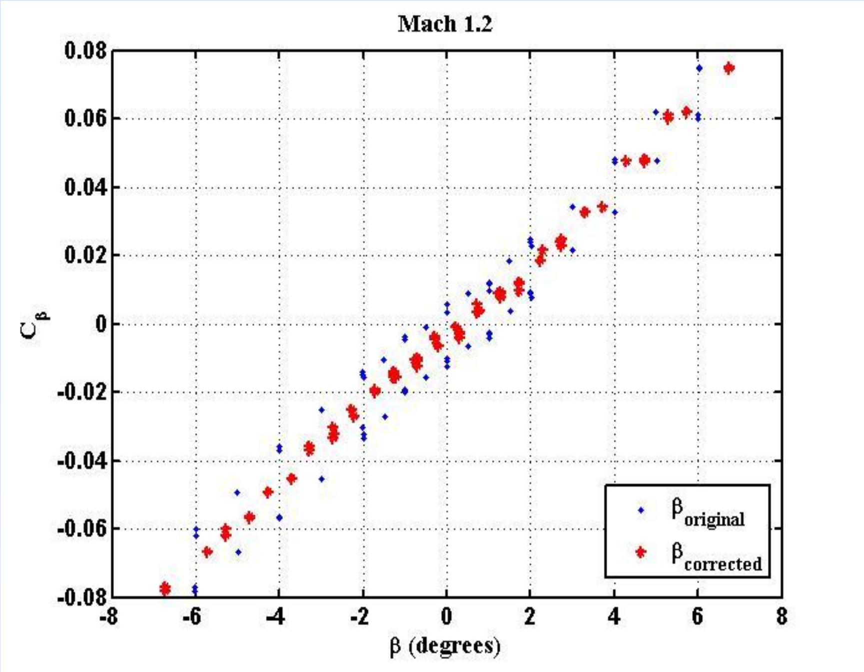
Angle of Attack (α)

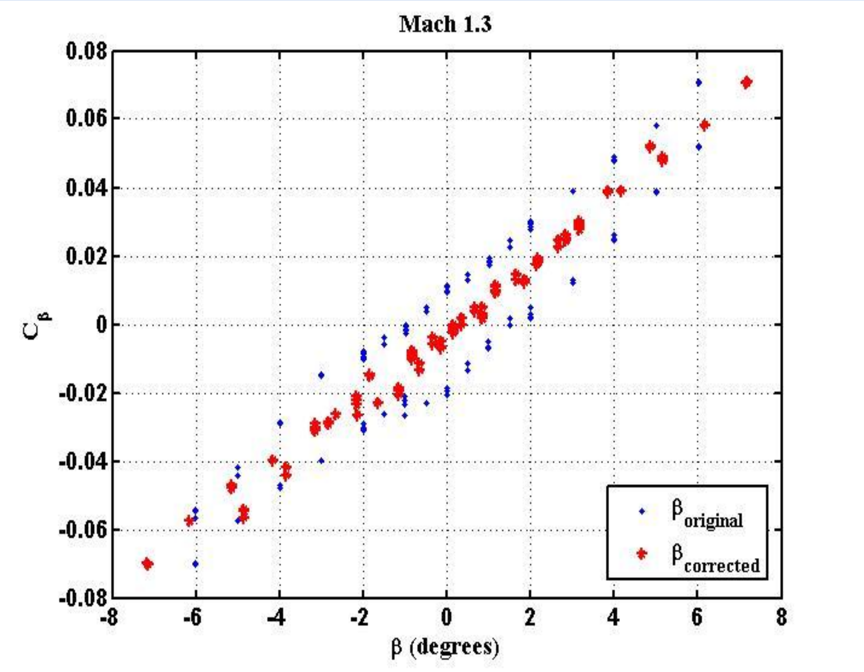




Determine α and β-Polynomials

Sideslip Angle (β)



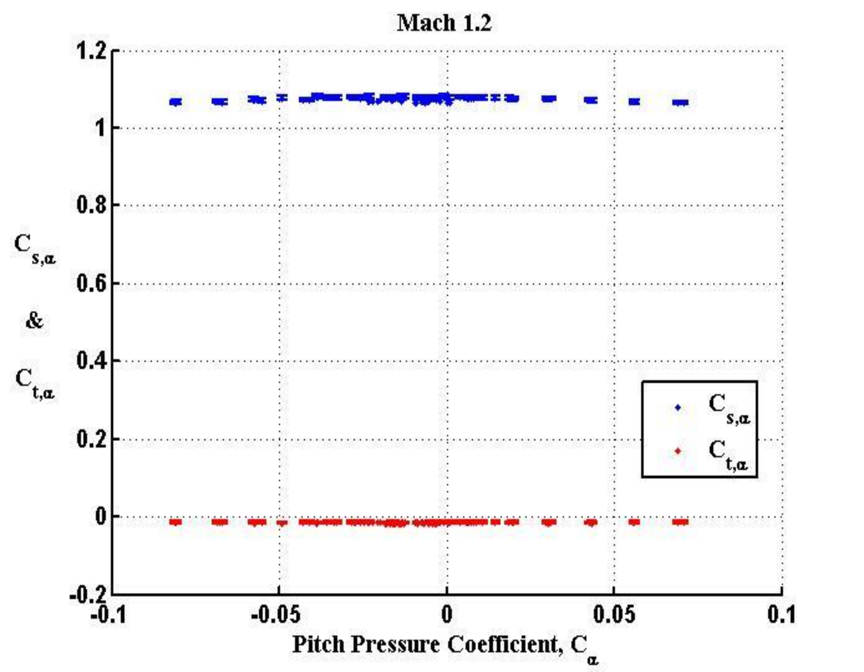


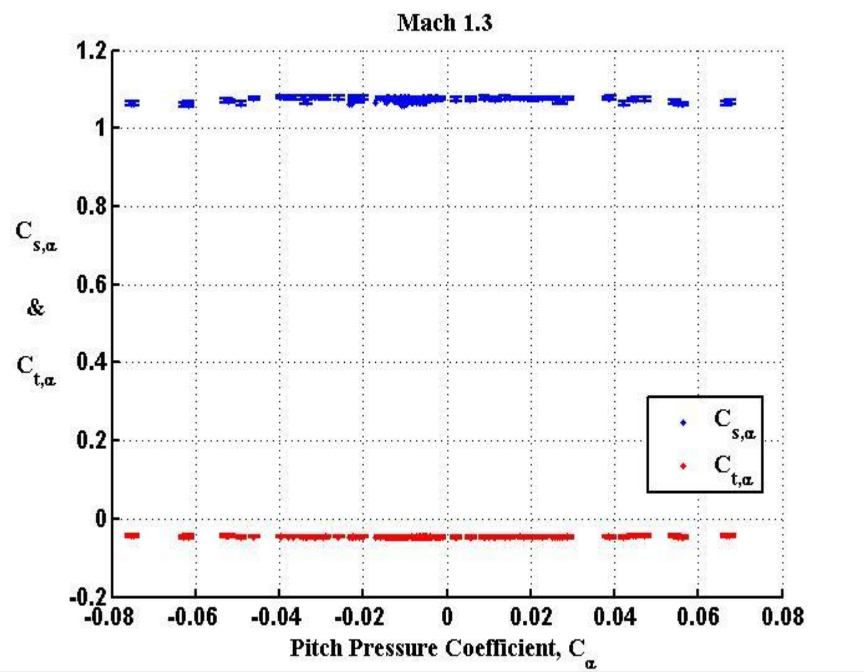
Verify Total & Static Pressure Coefficient Values

$$C_t = \frac{P_1 - P_o}{P_1 - P_a}$$

$$C_s = \frac{P_1 - P_s}{P_1 - P_a}$$

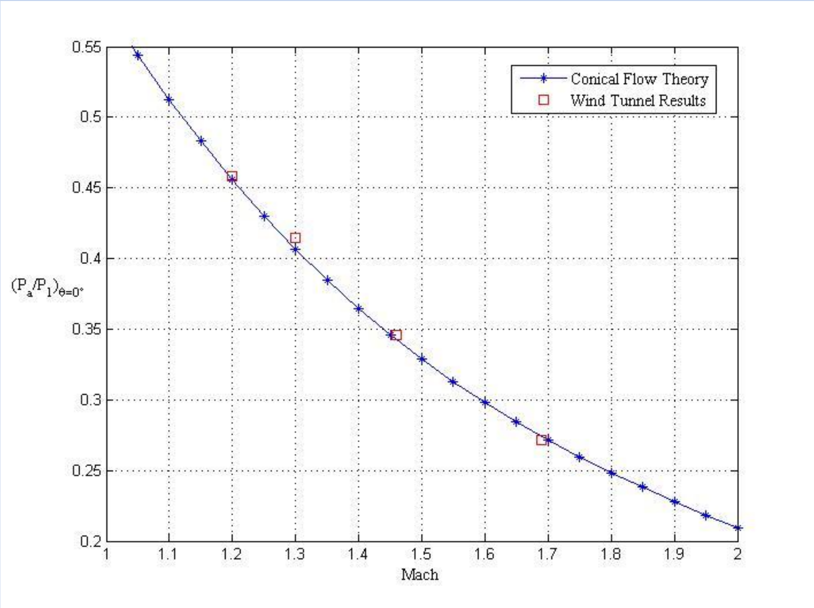
- For subsonic condition, $P_1 = P_{o,tunnel,}$ but for supersonic, $\mathbf{P_1 \neq P_{o,tunnel}}$
- Must take into account of presence of shocks at the probe.
- Angle of Attack Case Example:





Static-Pitot Pressure Ratio Comparison, P_a/P_1

- Compare values of $(P_a/P_1)_{\theta = 0°}$ for all Mach test conditions to its theoretical counterpart
- Values should descend with increasing supersonic conditions.
- Since wind tunnel results were close to theoretical, the conical flow theory curve will be used to estimate the initial local Mach number.

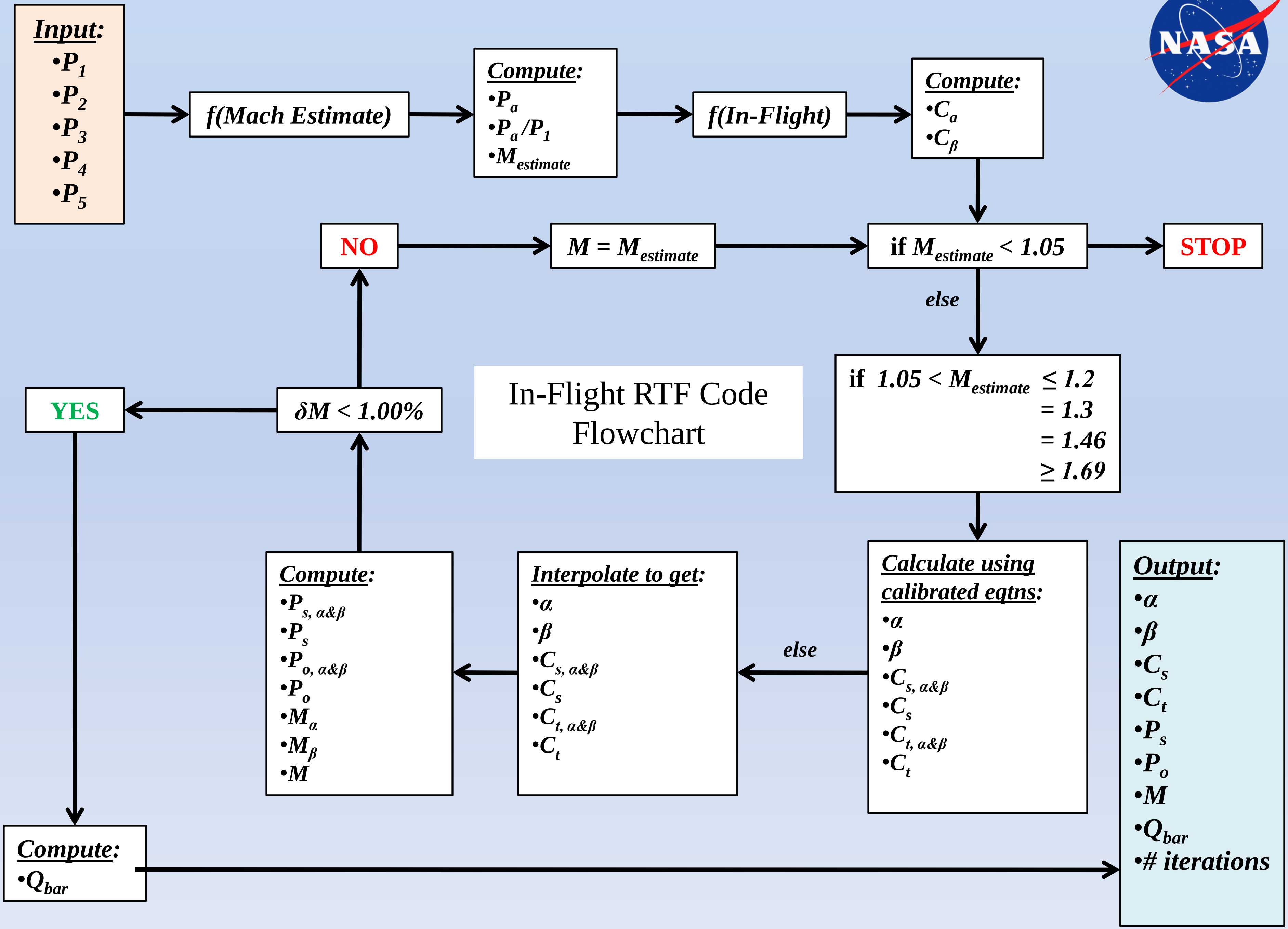


MACH	Theoretical	Wind Tunnel	Percentage Difference from Theoretical
1.20	0.4550	0.4579 ± 0.0008	+ 0.6374%
1.30	0.4067	0.4147 ± 0.0008	+ 1.9671%
1.46	0.3423	0.3457 ± 0.0008	+ 0.9932%
1.69	0.2739	0.2715 ± 0.0007	- 0.8762%

Uncertainty Analysis

- Three sources of uncertainty were obtained:
  - Marshall Space Flight Center Aerodynamic Research Facility (MSFC/ARF TWT) Mach number measurements
  - Error from Calibration Graphs
    - Derive standard deviation between the error difference from original wind tunnel data and corrected calibrated data
  - Uncertainty due to Error Propagation
    - Initial pressures have a rated error on them
    - Verified with MATLAB and hand calculations

		Mach 1.2	Mach 1.3	Mach 1.46	Mach 1.69
Wind Tunnel	α	-	-	-	-
	β	-	-	-	-
	Mach	0.0084	0.0110	0.0090	0.0095
	Q_{bar}	-	-	-	-
Calibration Graphs	α	0.15930	0.33860	0.23210	0.17710
	β	0.22770	0.28960	0.45720	0.27320
	Mach	0.00191	0.00388	0.00367	0.00340
	Q_{bar}	-	-	-	-
Error Propagation	α	0.29667	0.29695	0.31282	0.24138
	β	0.30081	0.31404	0.32548	0.24402
	Mach	0.00255	0.00274	0.00319	0.00353
	Q_{bar}	0.04778	0.05143	0.05851	0.07131
Combined Uncertainty Results	α	0.33673	0.45036	0.38952	0.29938
	β	0.37727	0.42719	0.56122	0.36631
	Mach	0.00898	0.01198	0.01023	0.01069
	Q_{bar}	0.04778	0.05143	0.05851	0.07131



In-Flight RTF Code Flowchart
Input: •P_1 •P_2 •P_3 •P_4 •P_5
f(Mach Estimate)
Compute: •P_a •P_a/P_1 •$M_{estimate}$
f(In-Flight)
Compute: •C_a •C_β
if $M_{estimate} < 1.05$
STOP
else
if $1.05 < M_{estimate} \leq 1.2$ $= 1.3$ $= 1.46$ ≥ 1.69
Calculate using calibrated eqtns: •α •β •$C_{s,\,\alpha\&\beta}$ •C_s •$C_{t,\,\alpha\&\beta}$ •C_t
else
Interpolate to get: •α •β •$C_{s,\,\alpha\&\beta}$ •C_s •$C_{t,\,\alpha\&\beta}$ •C_t
Compute: •$P_{s,\,\alpha\&\beta}$ •P_s •$P_{o,\,\alpha\&\beta}$ •P_o •M_α •M_β •M
$\delta M < 1.00\%$
NO
$M = M_{estimate}$
YES
Compute: •Q_{bar}
Output: •α •β •C_s •C_t •P_s •P_o •M •Q_{bar} •# iterations

Relation to Strategic Plan

- ***Goal S.1.1 – "Improve existing systems and processes for high value to our customers."***
- ***Goal S.2.1 – "Inform the aerospace and science communities of our skills and abilities."***
- ***Goal S.3.2 – "Create the necessary approaches to improve and/or expand capacity and capability."***

Other Activities

- Data analysis practice with SBLT, LMI, & EAP data
- Mission Control with Aero group during Eagle Aero Probe (EAP) flights
- Lots of technical reading
- Cal Poly Co-op/Senior Project
  – Daily Log
  – Periodic Progress Reports
  – Compiled a technical paper on my CCIE Co-op project to be presented along with this presentation upon return

Questions?